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SINTEF Ocean
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SFI Harvest is a centre for research-based innovation hosted by SINTEF Ocean. The centre has five research partners: SINTEF Digital, Nofima, NTNU, UIT (The Arctic University of Norway) and NMBU. The centre has 13 industry partners: Aker BioMarine, Br. Birkeland, Nordnes, ScanBio, Skretting, Kongsberg Maritime, PGS Geophysical, NCMC, Optimar, NCE Energy Valley, NAIS, Algen and NuasTechnology. The centre has an Advisory Board consisting of IFFO, REV Ocean, Norwegian Directorate of Fisheries, Norwegian Fishermen’s Association, Norwegian Fishermen’s Sales Organization for Pelagic Fish, and WWF Norway (associated partner). We are honoured to have formalised a cooperation with researchers at AZTI (Spain), University of Porto (Portugal) and Matis (Iceland).

During its first full year, the centre management has focused on establishing good management routines and platforms for R&D cooperation between researchers, industry partners, industrial bodies, and interest organisations in the centre. The year started with signing the Consortium Agreement. In February, the General Assembly (GA) and the Centre Board were consolidated. There have been two GA meetings and four centre board meetings during 2021. The Advisory Board has had two meetings. The centre management and research managers of SFI Harvest have had monthly status meetings.

During the year, project meetings have been arranged for researcher teams and for all partners. In the fall, we arranged a series of webinars presenting the scientific basis for SFI Harvest. The webinars were popular among all partners and this way of low-threshold presentations of state-of-the-art knowledge and research findings will be continued.

In October, a digital workshop was arranged for the centre partners presenting status and discussing R&D challenges regarding mesopelagic fisheries. The workshop resulted in an overview of basic challenges and problems related to development of a mesopelagic fishery which are addressed in a new project starting in 2022.

The first physical gathering for the partners in SFI Harvest were arranged in Trondheim, October 21-22. There were presentations of the research front relevant for the centre from both participants in SFI Harvest and invited guests. The status for the project activities within each research area were presented. The PhD and post doc candidates and their research topics were introduced to the centre partners. The partners got to know each other during group discussions about which R&D challenges to prioritise next. The input from the SFI Harvest days has been developed into work plans for next year.

The recruitment of research fellows is well underway. During 2021, three PhD candidates have started and one more has signed to start in 2022. We are proud to have an André Hoffman Fellowship associated with SFI Harvest.

Due to the covid-19 situation, most of the centre meetings and activities have been digital. This has likely delayed the process of establishing new collaborations across the research areas and between centre partners. Furthermore, cruise participations and experiments were cancelled due to the quarantine requirements. Despite this, important milestones were reached during the year.

The centre management acknowledges the efforts by all partners engaging in centre activities. We look forward to continuing the cooperation towards our common goals in SFI Harvest.
Vision and objectives

**Vision: Technology for sustainable biomarine value creation**

The main objective of SFI Harvest is to develop knowledge and technologies for responsible harvesting and processing of lower trophic marine resources, allowing sustainable growth of Norway’s biomarine industries.

The centre has the following secondary objectives:

- Conduct fundamental and applied research to close key knowledge gaps and enable responsible commercial utilisation of underexploited marine resources.
- Develop new competitive technologies to strengthen Norway’s global leading position in fisheries and marine knowledge, expertise, and technology.
- Establish profitable biomarine value chains and business models which are evaluated according to social, biological, and economical sustainability requirements.
- Explore cross-over applications to enable detection and collection of plastic and other polluting materials in the ocean.
- Build knowledge and competence capacity through education at least 10 PhD candidates, 3 post docs and 20 MSc candidates.
To establish sustainable value chains for exploiting the abundant resources of mesopelagic fish, zooplankton and phytoplankton, new knowledge is needed within six research areas (RA). Multidisciplinary research projects are designed based on two or more research areas.

**RA1**

**Survey technology - autonomous systems and sensor technology for data collection**

**Impact:** The knowledge generated will result in novel sensor technology and innovations that will enable cost efficient mapping and monitoring of concentrations of low trophic marine species, as well as marine waste.

**Research and innovation challenges:** 1) Continuous, unattended sampling of the concentrations of zooplankton, mesopelagic fish species and marine plastic litter/microplastic. 2) Surveying and monitoring of biomass and plastic concentrations using data-driven data collection strategies.

**RA2**

**Ecosystem dynamics**

**Impact:** Reliable prediction of potential hot spots for fishing that uses knowledge of important foraging areas for other mammals, birds, or fish. Predictability in spatiotemporal variability in ecosystem services are important for long term planning and sustainable management of undeveloped fisheries.

**Research and innovation challenges:** 1) Short term prediction of ecosystem characteristics for efficient and sustainable harvesting. 2) Long term prediction of ecosystem dynamics for sustainable management of low trophic species.
Digital decision support for fisheries

Impact: This research area will form the basis for new commercial fisheries decision support services allowing fishing vessels to save fuel and time, while improving the monitoring and understanding of the marine environment. This will contribute to fisheries sustainability and further innovation and business development.

Research and innovation challenges: 1) Combination of biomarine models and gathered data to generate information of value, such as predictions of future fishing areas. 2) Business models which encourage data sharing and the development of commercial decision support services in the fishing industry.

Harvest technology and onboard processing

Impact: Novel technology for effective and selective fishing, fractioning and onboard processing will improve efficiency and profit, as well as reduce waste. Selecting the right onboard handling and preservation methods will ensure high quality raw materials, further refined products, and ingredients. New harvesting technologies may also form a basis for novel tools for removing plastics from the ocean.

Research and innovation challenges: 1) Modelling the interaction between fish and harvesting equipment. 2) Cost-effective monitoring of harvest species while trawling. 3) Species and size selection during fishing. 4) Fractionation of the catch before onboard handling. 5) Cost- and energy-effective onboard preservation of mesopelagic species. 6) Cost-effective removal of plastics in the open ocean.

Land-based processing and product development

Impact: The outcomes of RA5 will form a solid foundation for commercial fishery and total utilisation of low trophic species. The work will identify the most promising land-based processing methods and products for realisation of the commercial potential of new bio-marine resources.

Research and innovation challenges: 1) For mesopelagic fish, the high level of autolytic activity and variable raw material quality causes increased energy consumption and reduced product quality. 2) For Calanus and krill, processing methods must be improved in terms of energy use, sustainability, and total utilisation. 3) Diversification of product portfolio and maximum value creation from harvested biomass. 4) In the development of new products from new species or through new processes, data on the nutritional quality, toxicological and microbial safety of novel food and feed products are needed.

Fisheries management and sustainable business models

Impact: The research area will provide input to management regimes for sustainable harvesting of lower trophic species and to the most viable and sustainable business models. A quantitative LCSA evaluation tool will be tailored for use during technology development and for the emerging biomarine value chains developed.

Research and innovation challenges: 1) A sustainable governance regime. 2) Efficient value chains. 3) Sustainable governance and business models.
The centre is organised as shown in the figure above. The general assembly, consisting of a representative from each partner, have the uppermost decision-making power in the centre.

The centre board consists of nine members among the centre partners. The centre board decide on organisation, budget, activities, working plans, and have the responsibility for the progress and scientific quality of the centre’s research activities.

**The members of the Centre Board (2020-2022)**

<table>
<thead>
<tr>
<th>MEMBER OF THE CENTRE BOARD</th>
<th>AFFILIATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sigve Nordrum (chair)</td>
<td>Aker Biomarine AS</td>
</tr>
<tr>
<td>Sigve Drønen</td>
<td>Br. Birkeland AS</td>
</tr>
<tr>
<td>Frank Tichy</td>
<td>Kongsberg Maritime AS</td>
</tr>
<tr>
<td>Einar Nielsen</td>
<td>PGS Geophysical AS</td>
</tr>
<tr>
<td>Mads Martinsen</td>
<td>Skretting AS</td>
</tr>
<tr>
<td>Monika Kopczyk</td>
<td>ScanBio Marine Group AS</td>
</tr>
<tr>
<td>Roar Bjånesøy</td>
<td>Norge Sildesalgslag SA</td>
</tr>
<tr>
<td>Gunvor Øie</td>
<td>SINTEF Ocean AS</td>
</tr>
<tr>
<td>Dina Aspen</td>
<td>NTNU</td>
</tr>
<tr>
<td>Anders Karlsson-Drangsholt (observer)</td>
<td>The Research Council of Norway</td>
</tr>
</tbody>
</table>
The Centre Board is advised by the Innovation Board and the Advisory Board. The Innovation Board is led by Vice President Katrine Vetlesen, Energy Valley. The Advisory Board advice on issues related to ethics, governance, regulations, and characteristics of the biomarine value chains.

Dr. Ingunn M. Holmen (SINTEF Ocean) is the Centre Director. The centre management group consists of the Centre Director, Research Area Managers for each of the six RAs and two coordinators.
**Partners**

The centre involves active cooperation between research partners and the Norwegian fishing sector, including fishing companies, technology developers and equipment suppliers, the main governmental body (Directorate of Fisheries) and relevant interest organisations. Addressing the research and innovation challenges in SFI Harvest requires a collaborative effort, sharing and integrating knowledge to develop technology for increased exploitation of low-trophic marine resources. The centre partners represent key user groups, technology providers, and internationally leading research institutes within the relevant fields. The industry partners have had a leading role in developing the current state-of-the-art concepts. Their collective experience and competence from the fishing and processing industry and marine and maritime sectors cover the identified key research areas. In 2021, SFI Harvest included three new consortium participants: NUAS Technology, Algen AS and NAIS.

**Industry partners**

<table>
<thead>
<tr>
<th>Industry partner</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aker BioMarine Antarctic AS</td>
<td>Experience and knowledge from many years of harvesting and processing krill. Vessel time for field studies, onboard lab use, metrics, and data storage.</td>
</tr>
<tr>
<td>Br. Birkeland AS</td>
<td>Experience and knowledge on pelagic and mesopelagic fisheries. Vessel time and fishing gear for mesopelagic fish.</td>
</tr>
<tr>
<td>Nordnes AS</td>
<td>Knowledge on harvesting mesopelagic species. Vessels time for field studies and validation of new technologies.</td>
</tr>
<tr>
<td>ScanBio Marine Group AS</td>
<td>Knowledge on how to ensile, store and transport fish silage, and share experience on production of silage made from mesopelagic fish, as well as three industry-scale productions of fish oil and fish protein concentrates.</td>
</tr>
<tr>
<td>Skretting AS</td>
<td>Knowledge of feed raw material and nutritional value.</td>
</tr>
<tr>
<td>Kongsberg Maritime AS</td>
<td>Expertise and systems for communication, control, navigation, decision support and AUVs.</td>
</tr>
<tr>
<td>PGS Geophysical AS</td>
<td>Competence on seismic exploration. Access to marine data and equipment relevant for use in the centre.</td>
</tr>
<tr>
<td>Norwegian Centre of Maritime Communication AS (NCMC)</td>
<td>Competence on internal and external communication, including interface between internal equipment over IP with secure remote support.</td>
</tr>
<tr>
<td>Optimar AS</td>
<td>Competence and equipment for the development of new processing equipment for mesopelagic fish and Calanus.</td>
</tr>
</tbody>
</table>
Energy Valley
Offering access to nearly 200 member companies of the cluster. These are also potential suppliers to the other partners.

Algen AS
Use of fishing vessel for Calanus harvesting, and validation of new technologies.

NUAS
Test production in hydrolysis pilot plant.

NAIS: North Atlantic Institute for Sustainable Fishing
Knowledge and network within the fisheries industry. Decision support systems for eco-based management and profitable fishing.

Advisory Board Partners

Norges Sildesalgslag SA
(Norwegian Fishermen’s Sales Organization for Pelagic Fish) Knowledge and data from current pelagic fisheries.

IFFO The Marine Ingredients Organisation Frontier knowledge on the marine ingredient industries.

Norges Fiskarlag
(The Norwegian Fishermen’s Association) Advice on technological innovations and governance issues in fisheries.

Directorate of Fisheries Advice on innovative development, industrial and scientific progress.

REV Ocean AS - REV Ocean will contribute with expert knowledge on the potential risks of targeting new fisheries resources and potential solutions to these risks. Furthermore, joint research cruises on the research vessel “REV Ocean” (in operation from 2022) will be enabled.

WWF (associated partner)
The SFI Harvest consortium will have a dialog with WWF (Worldwide Fund for Nature) in Norway about the sustainability of underexploited fisheries including low trophic species. WWF has strongly highlighted that there is a significant lack of knowledge on species-to-species interactions and species-to-habitat interactions.
Research partners

SINTEF Ocean AS (host institution)
Centre administration, research, and infrastructure within all research areas.

SINTEF Digital
Knowledge and competence in robotics and data analytics, in the areas of autonomy, adaptive sampling and machine learning.

Nofima AS
Research on processing and value creation from the harvested biomass and industrial economics in marine industries. Access to unique infrastructure.

NMBU – Norwegian University of Life Sciences
Competence on toxicology, fish health and -nutrition. Provides well-equipped laboratories.

NTNU Department of Marine Technology (IMT)
World-class fundamental research within the field of marine technology. Hosts the Centre for Autonomous Marine Operations and Systems (AMOS), a Norwegian Centre of Excellence.

NTNU Department of Engineering Cybernetics (ITK)
Research in various fields associated with control theory, including mathematical modelling and simulation, autonomy, optimisation, and automatic control. Plays a major role in AMOS.

NTNU Department of International Business (IIF)
A dedicated research team focusing on environmental sustainability analysis.

UiT – The Arctic University of Norway
Research within the modelling of productivity and fishing gear technology. Ship time on their research vessel.

Associated research partners

Matis
Research within harvesting, preserving, processing and value addition of key seafood resources.

University of Porto
- Knowledge on networked vehicle systems as well as state-of-art software toolchain for multi-domain vehicle systems. PU will make their fleet of over 16 autonomous underwater, surface and air vehicles available for experimentation and testing and will share data from experiments at sea.

AZTI
- Competence on oceanographic information and big data technologies for improvement of fishing efficiency, and competence on new marine resources such as mesopelagic fish.
Scientific activities and results

Autonomous systems and sensor technology for characterisation and data collection

Project manager: Martin Ludvigsen, NTNU IMT

To successfully harvest knowledge of the mesopelagic resources there are challenges of both instrumentation and communication together with data processing to address. This information can be used by autonomous systems to complement the prior information used to optimise the knowledge gained from deployment of unmanned systems. Even though these systems are expected to be cost efficient, the available samples are limited, and the sampling strategy need to be optimised. Making vehicles in the ocean able to sense the environment and use this information improve the sampling strategy on the fly will enable focus on interesting features like accumulation of plankton or strong oceanic gradients.

An important part of this work is to be able to provide accurate and quantifiable measurements of particles suspended in the water column. These particle data can be used for characterisation of lower trophic layers of the ecosystem. A combination of optical and acoustical instruments will be deployed for this task. These methods will also be deployed to detect anthropogenic particles like plastic. The potential for applying industrial ocean-going vessel to map the presence of ocean plastics together with autonomous systems will be investigated.

Objectives
The main objective is to develop technology for autonomous vehicles and sensor systems to support mapping and monitoring of underexploited marine resources. The following topics are defined for the work package:

1) How can machine vision be used for characterising the contents of seawater in situ?

2) How can multiple data collection platforms cooperate to efficiently survey a marine biomass?

Activities and results
In 2021, the first PhD student was hired to address both questions described above. Two different type of particle cameras have been deployed and tested to be developed further within the project – also in collaboration with the OceanLab project and the Nansen Legacy program. The aim of these imagers is to quantify and identify zooplankton like Calanus Finmarchicus.

Tests of autonomous underwater vehicles (AUVs) have been completed for the project. A vehicle equipped with both acoustic and optic sensors for identification of zooplankton is available for the project. It was deployed for training test and verification purposes – and together with PGS, a procedure for offshore launch and recovery from vessel of opportunity was shown.

Work has also been performed to define a proper framework for a centralised planner to handle multiple vehicles for mapping and characterisation of the mesopelagic resources.

Spatiotemporal variation in harvestable, low trophic biomass

Project manager: Dr. Ingrid Ellingsen, SINTEF Ocean

The biological, chemical, and physical processes in the ocean are tightly connected. Ocean phenomena such as eddies and fronts are for instance important for ecosystem structure and function and consequently for ecosystem efficiency. Existing knowledge, measurements and model systems will be used to assess variability in Calanus finmarchicus over a large range of spatial (meters to kilometres) and temporal (hours to years) scales. This knowledge is important to enable model systems with predictive capabilities that can be used in decision support.
A first version of algorithm detecting and tracking eddies from satellite Altimetry data developed.

A stage resolved population model for Calanus is set up and run for model configurations covering Arctic and Nordic waters. Results will be used for spatiotemporal analysis.

Hydrodynamic models established with 20 and 4 km resolution for Southern Ocean.

Impact/Innovation potential
The activity in the project is contributing to the societal outcomes from the UNESCO’s Decade of Ocean Science, and to a predictable ocean and a sustainable harvested ocean. This achieved improving knowledge and predictability of spatiotemporal dynamics of harvestable low trophic resources. The systems also provide data and information to decision support systems being developed in SFI Harvest.

Way forward
Statistical analysis of vertical distribution of *C. finmarchicus* will be carried out to increase our understanding of environmental drivers.

The eddy tracker will be further developed. The system will be tested in relation to catch data.

The work with developing and verifying the model systems will be continued based on existing knowledge, available data (open data and from SFI Harvest partners) and data being collected during cruises (planned in June 2022).

Decision support services basis

A fundamental assumption of this project was that the fishing industry can increase its value creation and reduce negative consequences, such as cost and environmental impact, if improved decision support is available.

By providing the basis for a platform for developing and providing decision support services, it is hoped that this project will contribute to a new business model where commercial actors provide services, fishing vessels provide data and researchers provide knowledge.
For identification of future decision support services, it was decided early on to base this on the work performed in the FishGuider research project. Due to the late inclusion of NAIS as a partner, this work was to be made available to the SFI Harvest late in the year. But the collection and distribution of vessel data, making existing data more easily accessible and to make predictions of fish availability was found to be promising areas.

A web service was established for demonstration purposes, both to assess technology choices and as a platform for showing future results. Screenshots are shown in the figure below. Figure 2 shows an operational web service presenting the results from SINMOD simulations. The data are updated every night and the service shows estimations and predictions from the previous 8 days and two days into the future. The user can choose between 16 layers and additionally choose between depth for some of these. Figure 3 shows a web service allowing the user to investigate recent catches in some detail. This service is based on matching catch reports and sales reports to establish catch data of sufficient detail and resolution. These sets of data are expected to be made available close to real time by the Norwegian Fisheries Directorate in the future, but for now this service is based on historic data.

Based on this work, the SFI Harvest project “Data driven fisheries planning” has been established and is expected to run from 2022 to 2023.
Selective harvesting technology for mesopelagic species

Project manager: Dr. Eduardo Grimaldo, SINTEF Ocean

The capture of mesopelagic fish species (fish, krill, Calanus sp.) is in its infancy, with severe lack of methods and equipment for both harvesting and onboard processing. New trawls for harvesting mesopelagic species are currently being developed, but their energy efficiency needs improvement. Although fishing gear has traditionally been developed iteratively using trial and error, research efforts have approached this challenge with more technological methods that combine modelling and control theory.

Activities and results

*Estimations of flow through fine-meshed nets and trawls.*

It was done using the theoretical model for the flow through fine-meshed nets and trawls as presented in Gjøsund and Enerhaug (2010). They derived basic relations for the flow through and forces on inclined net sections, based on pressure drop and streamline deflection through porous screens, and present parametric expressions for the filtration efficiency and drag on conical nets.

*Prediction models for size selectivity using the FISHSELECT and SELNET methodologies.* This provided optimal mesh sizes and mesh opening angles for trawl designs targeting specific mesopelagic species.

*Small scale testing of sampling methodology and new trawl designs.* The focus was on designing innovative sampling trawls for collection of mesopelagic samples from research and commercial cruises. It was carried out at SINTEF Flume tank in Hirtshals, Denmark. The resulting trawl was a modified HARSTAD trawl. The front part was a standard section of the HARSTAD trawl, but the belly and extension pieces were specially designed for collecting samples for
selectivity analysis with different mesh sizes simultaneously. The trawl had four bellies that were made with different mesh sizes (30, 20, 14 and 11 mm). The codends attached to the bellies were all similar and had 11 mm mesh size.

Collection of data onboard the research vessels Helmer Hanssen. A 14-day cruise was carried out off the coast of Northern Norway in the period June 20th – July 5th, 2021. Underwater video cameras were used to monitor the correct operation of the trawl, specifically to see the geometry in front of the four-belly section. Acoustic data, underwater video recordings and sampling catches was collected for further analysis. Characterisation of the catch and onboard processing experiments was carried out onboard and frozen samples were sent to SINTEF Sealab, NOFIMA and AZTI for further analysis.

Chemical analysis of frozen catch samples collected from earlier commercial cruises have been analysed.

The results will be published in scientific articles which are under preparation.

Impact/Innovation potential
Mesopelagic fish, krill and Calanus are perishable commodities which enter a series of degradation processes upon death. The speed of these processes depends on species composition and fish properties, handling, storage conditions and processing. The catches are today preserved mainly by cooling, but new methods are needed to delay the breakdown and increase the value of the biomass.

Total utilisation of North Atlantic krill

Project manager: Dr. Birthe Vang, Nofima

There is potential for harvesting and utilization of the northern krill biomass, *Meganyctiphanes norvegica*, focusing on the use of the entire biomass, including oil, protein, and solid fractions (e.g., chitin). By providing diversification of product portfolio a maximum value creation from harvested biomass can be obtained. And by ensuring total utilization, the harvesting can be as sustainable as possible. The product possibilities are dependent on fishing and conservation. For mesopelagic species, the high level of autolytic activity and variable raw material quality causes increased energy consumption and reduced product quality. Processing methods for mesopelagic species like krill must be improved towards sustainability by reducing energy use and reduce biomass loss. In the development of new products from new species or through new processes, it is important to identify the nutritional quality, toxicological and microbial safety, the presence of contaminants and other undesirable components like plastic to ensure safety of novel food and feed products.

Objectives
The main objective of this project was to characterise the nutritional and other components in krill and krill products, and to develop sustainable options for commercial products from north Atlantic krill through cost and energy efficient
processes. We also wanted to perform pilot scale processing of krill products to be able to evaluate possible marked directions for the products.

**Activities and results**

PhD student Maria Alquiza Madina was hired at SINTEF Ocean. Her focus area will be production of ingredients from little utilised and low trophic species. A PhD position at NMBU was announced.

Protocols for silage preservation on board as well as protocol for collecting samples for microplastic analysis was established, and samples of different mesopelagic species were collected during a research cruise with Helmer Hanssen related to RA4 in June 2022. The samples were preserved in different ways, included silage, liquid nitrogen and freezing at -20°C (table). There was also establish a list of suggested analyses of nutrient compositions of to be performed on mesopelagic mixed catches and fractions. This includes proximate composition, detailed macronutrient composition, vitamins and vitamin-like compounds and trace elements.

**Overview of samples taken during research cruise with Helmer Hanssen in June 2022.**

<table>
<thead>
<tr>
<th>EXPERIMENT</th>
<th>SPECIES</th>
<th>TOTAL WEIGHT (G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silage</td>
<td>Benthosema glaciale</td>
<td>1768</td>
</tr>
<tr>
<td>Silage</td>
<td>Krill</td>
<td>896</td>
</tr>
<tr>
<td>Liquid N2</td>
<td>Benthosema glaciale</td>
<td>1320</td>
</tr>
<tr>
<td>Liquid N2</td>
<td>Krill</td>
<td>1572</td>
</tr>
<tr>
<td>Liquid N2</td>
<td>Maurolicus muelleri</td>
<td>24</td>
</tr>
<tr>
<td>Liquid N2</td>
<td>Calanus</td>
<td>304</td>
</tr>
<tr>
<td>Liquid N2</td>
<td>Benthosema + krill</td>
<td>102</td>
</tr>
<tr>
<td>Liquid N2</td>
<td>Shrimp</td>
<td>60</td>
</tr>
<tr>
<td>-20°C</td>
<td>Benthosema glaciale</td>
<td>7885</td>
</tr>
<tr>
<td>-20°C</td>
<td>Krill</td>
<td>4330</td>
</tr>
<tr>
<td>-20°C</td>
<td>Blue whiting</td>
<td>3282</td>
</tr>
<tr>
<td>-20°C</td>
<td>Shrimp</td>
<td>98</td>
</tr>
<tr>
<td>-20°C</td>
<td>Mix catch</td>
<td>6970</td>
</tr>
</tbody>
</table>

Due to limited amount of biomass obtained from the research cruise (table), some of the planned activities had to be altered or postponed. The pilot scale processing could not be carried out, which also affected the production of anticipated products. The results from product quality analysis, (i.e., specific ingredients etc) would determine priorities within marked research. The planned marked evaluation of products was replaced by ongoing analysis of information from VitaFoods 2021 and SupplySide West 2021 (N-America) specifically related to feed, supplement and food ingredient markets.

Ongoing experiments are using silage technology as an alternative for preservation of the raw material straight after catch. The following silage tests were performed using samples collected during research cruise (June 2021). 1) Silage experiment started on board of the research cruise with Helmer Hanssen with samples of krill and fish (*Benthosema glaciale*). After the cruise, the samples were stored for further analysis. 2) After freeze storage (October 2021) the corresponding samples were thawed and mixed with formic acid to start silage. Both groups on silage experiment were stored 3 months and 6 months at 10°C before fractionation and further analysis. Samples from silage experiment have been analysed for mass balance, dry matter, ash, water. Analyses for protein content, lipid classes, fatty acid composition, lipid content, quality of obtained oil (PV and AV), contaminants of emerging concern, POPs and heavy metals are under execution. The results from the silage storage trials including quality changes will be published in a pending manuscript, expected to be submitted in 2022.

Because of the limited amount of raw material, it was decided to evaluate the quality of Mueller’s pearside collected in 2019 with aim of conduction feeding trials to evaluate digestabiligy in Atlantic salmon. Both thermal and hydrolysis technologies were used to process the raw material. Chemical extraction (B&D method) was also performed. Lipid analyses (FFA, PV, AV, TBARS) indicated that degradation processes had taken place during storage of raw material at -28°C, leaving the raw material in sub optimal condition. Based on these results it was decided to perform technological and feeding tests on fresh raw material which most probably will be collected during planned research cruise in June 2022.

**Impact/innovation potential**

The outcomes of RA5 will form a solid foundation for commercial fishery and total utilisation of low trophic species. The work will identify the most promising land-based processing methods and products for realisation of the commercial potential of new bio-marine resources.

**Way forward**

The work ahead is depending on supply of enough raw material to complete processing trials so that processing
parameters, yield and quality of products can be investigated.

We aim to collect mesopelagic fish and krill samples from different seasons to be able to describe seasonal variation (chemical composition, enzymatic activity etc.) in different species. As part of this, supply of frozen krill samples has been provided by Matis and are expected to arrive in March 2022.

We are planning to start feeding trials to determine digestibility and growth of Atlantic salmon (*Salmo salar*) fed feed with inclusion of mesopelagic species. The feeding trials will be conducted at Havbruksstasjonen in Tromsø (aquaculture research station in Tromsø). Processing and analysis of the raw material will be performed to ensure quality of the feed. Feed will be produced at Skretting research production facilities.

**Management and value chains of low trophic fisheries**

*Project manager: Dr. Bent Dreyer, Nofima*

Low trophic fisheries must be adapted to an ecosystem-based management approach, which comply to the principles of sustainable fisheries management. For new mesopelagic and lower trophic fisheries in the North-Atlantic, the knowledge about biology and biomass is still insufficient for determining sustainable quotas and technical rules for harvesting and the fishing activity of these species are therefore limited. This also means that the knowledge basis for choosing efficient business models is missing. Although different models for vertical integration exists in Norwegian fisheries, the dominant business model constitute separate ownership to vessels and processing plants, as independent transaction partners of fish in the first-hand markets. This is, however, predicted to be inefficient if applied to new lower-trophic fisheries.

Antarctic krill and *Calanus finmarchicus* in Norway are two species that currently are being harvested by Norwegian vessels. Antarctic krill has a well-established fishery management regime governed by the commission of the Conservation of Antarctic Marine Living Resources (CCAMLR). The management plan for *Calanus finmarchicus*, however, is newly implemented within the institutional frames of the Norwegian management regime. These two fisheries will be studied in detail, both in terms of how they are governed, and how the value chains are organised in terms of ownership product, process operation and portfolios. The intention is to establish knowledge that are important input for establishing a LCSA framework for business models based on mesopelagic fisheries and to reveal challenges facing sustainable governance of mesopelagic fisheries in North Atlantic.

**Objectives**

- Establish a knowledge base for existing governance of mesopelagic species
- Study current business models for mesopelagic fisheries
- Identify challenges in the governance of mesopelagic species in Norway
- Recruit a PhD candidate that will perform a LCSA framework for business models based on mesopelagic fisheries

**Activities and results**

Three projects have been initiated in 2021 as described in the illustration (Figure 4). The projects are all well integrated into planned activities in all the SFI Harvest research areas. In the first project a literature review has been conducted of well-established governance structure in commercial harvesting of low trophic species, and how to adapt low-tropic fisheries to other TAC-regulated fisheries. This is an important milestone in establishing a sustainable
Complementary projects

**CalaFeed: Enhancing the potential of Calanus as raw material for sustainable aquaculture feed ingredients – SINTEF**

*Project manager: Dr. Inger Beate Standal, SINTEF Ocean*

The main goal of the CalaFeed project is to enhance the potential of *Calanus finmarchicus* as an aquafeed ingredient. CalaFeed is being coordinated by SINTEF Ocean, together with research partners Nofima, NTNU, and CSIC (Spain), as well as the industry partners Zooca AS and Skretting. The project is financed by the Norwegian Research Council (KSP: NFR 320536). Research activities regarding on-board handling and processing are being coordinated with SFI Harvest. Currently silage experiments are optimised at SINTEF to gain more knowledge on the effect of this possible on-board handling method for producing protein rich feed ingredients without compromising the quality of the oil. Protein ingredients (such as hydrolysate, meal or ensiled proteins) will be tested out in fish feeding trials at Nofima/ Skretting facilities, and a post-doc at NTNU is dedicated for sustainability analysis of *C. finmarchicus* feed ingredients.

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governance structure for new mesopelagic species in North Atlantic.

The second project have studied how the value systems are organised and the product portfolios from these fisheries. This is important to reveal challenges in organising the value systems in an efficient and sustainable way when establishing an industry based on fisheries yet to be open.

The third project is to prepare implementation of a LCSA framework in different business models applied in commercial fisheries and value systems studied. The LCSA framework is postponed – because recruiting of a PhD student has been delayed.

In 2021, a literature review on mesopelagic fisheries has been published. Furthermore, a thorough analysis of Norwegian fishing for Calanus has been carried out in terms of management regime and resource allocation. In addition, the development of landings and harvest strategies are revealed. The study showed that activity has been very low since the management plan was introduced and new licenses were awarded. The reasons for this may be several. Catch rates and more profitable activity in alternative fisheries in the high season for fishing for Calanus are two important explanations that are highlighted in the study. These are also factors that are emphasised in the literature review focusing on why catches are low globally of mesopelagic species.
Antarctic krill and Calanus finmarchicus in Norway are two species that currently are being harvested by Norwegian vessels.
The post doc held by Dr. Katherine Crosman is financed as a cooperation between the World Economic Forum’s Andre Hoffmann Fellowships for the Fourth Industrial Revolution, NTNU, SFI Harvest and C4IR Ocean.

The international cooperation gives the Norwegian industry partners access to scientific knowledge in important areas for the innovation activities in the centre: AUV, autonomy, sensor technology, oceanography, ecology, harvesting and processing technology. It also ensures a tight link with the EU projects MEESO and SUMMER which both target mesopelagic fisheries. Future cruises and complementary research activities have been coordinated.

The University of Porto, AZTI and Matis are associated participants in the centre’s research and innovation activities. In 2021, they were invited to webinars and relevant digital and physical meetings.

During the SINTEF Harvest days in October, the three international partners were represented in Trondheim and contributed with state-of-the art lectures within their expert fields.

International cooperation
Oceanography to achieve the main objective and thus increase the present knowledge of zooplankton ecosystem dynamics.

Industry applications
Calanus finmarchicus is one of the most studied zooplankton species in the North Atlantic and is of great importance for the development of species of commercial interest such as herring, mackerel, blue whiting, mesopelagic fish, etc. Therefore, investigating their distribution and their relationship with hydrographic variables will help to predict and locate populations of both zooplankton and higher trophic levels of commercial interest.

Eva is currently working meta-analysis of Calanus finmarchicus vertical distribution and its relationship with hydrographic variables and chlorophyll concentration in the upper layer of the North Atlantic basin. She is also investigating C. finmarchicus aggregations (patches) variability and its relationship with environmental variables using the coupled physical-biological ocean model SINMOD and LOPC data.

Karoline’s work will involve developing a pool of combined sensors to cover the range of particle sizes among plankton, especially in the zooplankton size ranges involving copepods and krill. Particle imaging and development of algorithms for detection, classification, and biomass estimations of these species, based on machine learning techniques, will be in focus. Biomass estimations will further be a part of systems for adaptive mission planning in heterogeneous networks, i.e., networks of vehicles from different domains (e.g., aerial, surface, and under-water vehicles).

By adaptive mission planning, the platforms’ paths during a mission are modified to explore the locations with the highest calculated information value, here, in terms of mesopelagic species, particularly plankton, biomass. Algorithms for adaptive mission planning will be developed specifically for this domain.

Eva’s research questions are focused on the study of the spatial and temporal distribution of zooplankton and specifically the copepod species Calanus finmarchicus in the Norwegian Sea. Her doctoral proposal has a multidisciplinary scope including areas such as underwater acoustics, biology, ecology, modelling, statistics, or general oceanography to achieve the main objective and thus increase the present knowledge of zooplankton ecosystem dynamics.

Industry applications
Calanus finmarchicus is one of the most studied zooplankton species in the North Atlantic and is of great importance for the development of species of commercial interest such as herring, mackerel, blue whiting, mesopelagic fish, etc. Therefore, investigating their distribution and their relationship with hydrographic variables will help to predict and locate populations of both zooplankton and higher trophic levels of commercial interest.

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Karoline Barstein (PhD candidate)
Mesopelagic resource estimation in adaptive mission planning with heterogeneous platforms

Eva Chamorro Garrido (PhD candidate)
Spatial-temporal variability of Calanus spp. Populations and its relationship with hydrographic variables in the Norwegian Sea

Maria Alquiza Madina (PhD candidate with other financial support)
Development of innovative solutions for high value-added products from low trophic marine species

Maria has studied both Marine Biology and Food Science. Her PhD is within the Biotechnology and Food Science program at NTNU, and her research is focused on utilisation of low trophic marine species, mainly mesopelagic species, with the aim of getting new marine ingredients and apply the best technologies to ensure their quality. The main objective of Maria’s present PhD project is the development of handling, preservation and processing methods for utilization and management of stability and quality of under-utilised low trophic marine species.
Given the major knowledge gaps in the biology and ecology of low trophic marine resources, the characterisation of the species will play an important role in defining its potential. Furthermore, new methods are needed to preserve the catches and thus delay upon death perishable processes. Setting appropriate onboard handling, processing and preservation methods will improve the quality and profit of the raw materials. The PhD-project will contribute with knowledge generation and addressing some of the main issues in the early stages of the value chain to ensure maximum yield, quality, and use of resources.

Goals:
1. Identify the relevant stakeholder landscapes, and the path from data collection to action followed by Big Data from a heterogeneous network of sensor-carrying platforms operating in space, in the air, on the sea surface, and in the water column, including under ice.
2. Identify barriers to trustworthiness and trust in these data, as experienced by key stakeholders identified in Stage 1.
3. Identify and experimentally test theoretically- and empirically derived strategies to address the barriers identified in Stage 2.

Kate holds a PhD in Public Policy and Management from the University of Washington and an MSc in Natural Resources and Environment from the University of Michigan. Dr Crosman has an André Hoffman Fellowship with NTNU AMOS, the World Economic Forum’s Ocean Action Agenda, the centre for the 4th Industrial Revolution – Ocean, and SFI Harvest. Her fellowship focuses on addressing barriers to trustworthiness and trust in big data for oceans.

Big Data has the potential to transform decision-making, governance, and management of oceans. However, the tools used to process, store, manage, analyse, and communicate Big Data may raise trust issues among key stakeholders. Trust issues may further interact with pre-existing stakeholder relationships, values, and knowledge to undermine decision-making and support for ocean governance.

This series of studies will examine trustworthiness and trust in Big Ocean data with reference to lower trophic-level fishery cases (e.g., Calanus finmarchicus in the Norwegian Sea; krill in the Southern Ocean).

Enis Noyan Kostak is a PhD candidate in SFI Harvest. He holds an MSc in Fishing Technology from Ege University. He worked as a research fellow in Ege University on DEEPSEA Photonic Sensors project. The activities in his PHD are aimed at developing selective harvesting technologies for mesopelagic species. Specifically, this PhD project will be focusing on: Designing energy efficient small-mesh trawls for mesopelagic species (fish, krill, Calanus), assessing the effect of trawl designs parameters (tapering angle, mesh size, mesh opening angle) on catch efficiency and selectivity of target and bycatch species, and understanding the interaction between potentially important mesopelagic species (i.e., fish, krill and Calanus) and new trawl designs. Enis will start his studies in 2022.
Communication and dissemination activities

SFI Harvest news and updates
The centre actively communicates its activities and results to the industry, the scientific community, and the general public. Information flow, communication, and demonstration of development in the centre is an important administrative task for SFI Harvest. Detailed communication activities will be announced each year based on the Centre’s Communication and Dissemination Plan.

Media
Media is an essential communication channel for SFI Harvest. In March 2021 we published our first article in Gemini. We have also published articles on sintef.no. As we get more results, we will continue to write press releases to get more media attention.

Website
A project webpage (www.sfiharvest.no / www.sfiharvest.com) has been established to present information about and news from the centre to both internal and external target groups. The website contains public information about the centre. News is also administered on the website.

Social media
The SINTEF Ocean Facebook page (www.facebook.com/ sintfocean) and LinkedIn profile (www.linkedin.com/ company/sintfocean) is being used to further promote news from the centre. Both Facebook and LinkedIn pages link to new articles from the webpage, in addition to presenting other relevant information that is not available on the webpage.

Webinars
SFI Harvest arranged a series of webinars in the fall of 2021 to keep partners regularly updated on scientific progress and maintain the dialog between research team and industry partners. More webinars will follow in 2022.

Professional journal and feature articles, podcasts, and blogs
The objective of the seminars was to present the state-of-the-art knowledge for the R&D activities in SFI Harvest.

**Webinars**

In the autumn of 2021, six weekly video seminars were held each Friday from Sept 3rd to Oct 8th. The webinars consisted of 2-3 speakers and time for questions from the participants and discussion.

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<td>RA1 Survey technology</td>
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<td>RA2 Ecosystem dynamics</td>
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<td>8/10</td>
<td>RA6 Governance and sustainable business models</td>
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Information flow, communication, and demonstration of development in the centre is an important administrative task for SFI Harvest.
Publications

Journal papers

### Key personnel

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<th>KEY PERSONNEL</th>
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<tr>
<td>Ingunn M. Holmen</td>
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<td>Hilde Wanvik</td>
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<td>Kaja Haug</td>
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* Nofima AS, SINTEF Digital, UiT-The Arctic University of Norway, Norwegian University of Science and Technology (NTNU), Norwegian University of Life Sciences (NMBU)
